STRUCTURAL BEHAVIOUR OF PRECAST LIGHTWEIGHT FOAMED CONCRETE SANDWICH PANEL (PLFP) WITH SHEAR TRUSS CONNECTORS

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DEDICATION

For my beloved family, friends and supportive supervisors

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ABSTRACT

Precast system is playing a very important role in industrialize building system to construct more affordable and quality houses to meet the high demands. Many researches have been carried out to develop precast sandwich wall panel with more benefits such as lighter in weight, environmental friendly and easy to construct compared to normal reinforced concrete panel. Therefore, a study was carried out to develop Precast Lightweight Foamed Concrete Sandwich Panel (PLFP) with shear truss connectors. The objectives of this study are to numerically investigate the PLFP panel with single and double shear truss connectors to determine its structural behaviour with validation from experimental work and to develop the empirical equation to predict its ultimate strength under axial load. PLFP panel is made of foamed concrete as the outer wythes which enclose a core layer of polystyrene. The wythes were reinforced with steel bars and tied to each other through the polystyrene layer by using steel shear connectors (bent at an angle of 45°). Experimental testing had been conducted to determine the material properties of foamed concrete and steel bar and used for PLFP model in finite element analysis. Eight half scaled PLFP panels were tested experimentally under axial load until it failed. Ultimate load carrying capacity, load lateral deflection profile, strain distributions and failure mode were recorded. Finite element analysis was carried out on PLFP panels which were validated with experimental results. Full scaled PLFP panels with single and double shear truss connectors had been studied numerically to investigate the effects of geometrical imperfection, slenderness ratio, thickness, and shear connectors toward its structural behaviour. From the results, it was found that when the rate of geometrical imperfection and slenderness ratio of PLFP panel increased, the ultimate load of PLFP panel decreased. The use of double shear truss connectors indicated improvement in the PFLP's strength and stability under axial load and longitudinal shear force compared to single shear truss connectors. An empirical equation which was modified from previous research is proposed to predict the ultimate load carrying capacity of PLFP under axial load.

ABSTRAK

Sistem pratuang memainkan peranan yang penting dalam sistem bangunan pra fabrikasi di kilang untuk membina lebih banyak rumah mampu milik dan berkualiti untuk memenuhi permintaan yang tinggi. Banyak kajian telah dijalankan untuk membangunkan panel pratuang *sandwich* dengan lebih banyak faedah seperti lebih ringan, mesra alam dan mudah untuk dibina berbanding panel konkrit bertetulang yang biasa. Oleh itu, satu kajian telah dijalankan untuk membangunkan Panel Pratuang *Sandwich* dari konkrit ringan berbusa (PLFP) dengan penyambung ricih kekuda. Objektif kajian ini adalah untuk menyiasat panel PLFP dengan penyambung ricih kekuda tunggal dan berganda bagi menentukan kelakuan struktur panel berdasarkan unsur terhingga dengan pengesahan dari eksperimen dan untuk menerbitkan persamaan empirikal bagi meramalkan kekuatan muktamad yang boleh ditanggung di bawah beban paksi. Panel PLFP diperbuat daripada konkrit berbusa sebagai lapisan dinding luar dan polisterin sebagai lapisan dalam. Lapisan dinding luar telah diperkukuhkan dengan bar keluli dan terikat kepada satu sama lain melalui lapisan polisterin dengan menggunakan penyambung ricih kekuda keluli (dibengkokkan pada sudut 45°). Eksperimen telah dijalankan untuk menentukan ciri-ciri bahan konkrit berbusa dan keluli bar bagi digunakan untuk memodelkan PLFP dalam analisis unsur terhingga. Lapan panel PLFP yang berskala separuh telah diuji dibawah beban paksi sehingga ia gagal. Panel PLFP telah dikaji dengan menggunakan analisis unsur terhingga untuk menyiasat kesan ketidaksempurnaan geometri, nisbah kelangsingan, ketebalan, dan penyambung ricih ke atas tingkah laku strukturnya. Daripada hasil kajian, apabila kadar ketidaksempurnaan geometri dan nisbah kelangsingan panel PLFP meningkat, beban muktamad panel PLFP menurun. Penggunaan penyambung ricih kekuda berganda menunjukkan peningkatan dalam kekuatan dan kestabilan panel PFLP di bawah beban paksi dan daya ricih membujur berbanding kekuda penyambung ricih tunggal. Persamaan empirikal yang telah diubahsuai daripada persamaan empirikal yang diterbitkan dalam kajian terdahuhu telah dicadangkan untuk meramal beban muktamad PLFP bawah pengaruh beban paksi.

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LIST OF SYMBOLS AND ABBREVIATIONS

b	-	Overall width of the cross section
B	-	Length
c/c	-	centre to centre
C	-	Concrete cover
D	-	Damage parameter
e	-	Eccentricity
E	-	Young's Modulus
h	-	Overall depth of the cross section
H	-	Height of panel
$\frac{H}{B}$	-	Aspect ratio
$\frac{H}{L}$	-	Aspect Ratio
$\frac{H}{t}$	-	Slenderness ratio
k	-	0.8 for wall brace top and bottom against lateral translation and restrained against rotation at one or both ends.
K	-	The ratio of the second stress invariant on the tensile meridian
pcf	-	*per cubic foot*
t	-	Overall Thickness
Ψ	-	Dilatation angle
σ	-	Stress
$\frac{\sigma_{bo}}{\sigma_{co}}$	-	The ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress
σ_{c0}	-	Initial yield
σ_{cu}	-	Ultimate stress
σ_{max}	-	Maximum principal effective stress
σ_{t0}	-	Uniaxial tensile stress at failure
ε	-	Strain
ε_t^{pl}	-	Tensile equivalent plastic strains

ε_c^{pl}	-	Compressive equivalent plastic strains
ϵ	-	Flow potential eccentricity
η	-	Effective length factor, 1.0 for compressive strength of concrete at 28 days ≤ 50MPa
ρ	-	Density
υ	-	Poisson Ratio
μ	-	*Viscosity parameter*
θ	-	Temperature
Φ	-	Diameter of shear connector (mm)
Φ	-	The strength of reduction factor (0.7 for reinforced member)
Ø	-	Factor taking into account curvature, including second order effects
ASTM	-	American Standard Test Method
BCA	-	British Cement Association
BS	-	British Standard
CFRP	-	Carbon Reinforced Polymer
CIDB	-	Construction Industry Development Board of Malaysia
CREAM	-	Construction Research Institute of Malaysia
C3D8R	-	Continuum three dimensional 8 node linear brick element
EC2	-	Eurocode 2
EPS	-	Expanded Polystyrene foam
EXP	-	Experimental Result
FE	-	Finite element
FEA	-	Finite Element Analysis
HA	-	Half scale panel
IBS	-	Industrialized Building System
LVDT	-	Linear Voltage Displacement Transducers
PCI	-	Precast Concrete Institution
PLFP	-	Precast Lightweight Foamed Concrete Sandwich Panel
PRIMA	-	1 Malaysia People's Housing Programme
PSI	-	Pounds per square inch
PS	-	PLFP with single shear truss connectors
R&D	-	Research and Development
R3D4	-	Three dimensional 4 nodes rigid element

R3	-	3 mm mild steel
R6	-	6 mm mild steel
SG	-	Strain Gauges
T3D2	-	Three dimensional 2 nodes truss element
UTHM	-	Universiti Tun Hussein Onn Malaysia
XPS	-	Extruded Polystyrene foam
A_c	-	The gross area of section
A_{sc}	-	The total area of steel used
A_{st}	-	Total area of longitudinal reinforcement
d_c	-	uniaxial damage variable due to compression
d_t	-	uniaxial damage due to tension
E	-	Modulus Young
E_o	-	Initial (undamaged) elastic stiffness/ initial modulus of the material
e_a	-	An additional eccentricity due to deflections in the wall
e_i	-	Additional eccentricity covering the effects of geometrical imperfection
e_o	-	First order of eccentricity
e_{tot}	-	$e_o + e_i$
f_{bo}/f_{co}	-	The ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress
f_{cu}	-	The compressive strength of concrete
f_i	-	field variable
f_y	-	The tensile strength of the steel
G	-	Flow potential
J	-	Energy
K_c	-	The ratio of the second stress invariant on the tensile meridian
l_o	-	Effective length of the wall
N_u	-	Design axial strength per unit length of wall (N/mm)
N_{Rd}	-	Axial resistance of wall
p	-	Hydrostatic pressure stress
P_u	-	The ultimate strength of panel
q	-	Mises equivalent effective stress
σ_y	-	Initial yield

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